

ES-3100: A NEW GENERATION SHIPPING CONTAINER FOR BULK HIGHLY ENRICHED URANIUM AND OTHER FISSILE MATERIALS

Jeffrey G. Arbital

HEU Disposition Program Office
BWXT Y-12, LLC

Gerald A. Byington

Y-12 Packaging Engineering Group
BWXT Y-12, LLC

Dean R. Tousley

Office of Fissile Materials Disposition
National Nuclear Security Administration

ABSTRACT

The U.S. Department of Energy (DOE) National Nuclear Security Administration (NNSA) is shipping bulk quantities of surplus fissile materials, primarily highly enriched uranium (HEU), over the next 15 to 20 years for disposition purposes. The U.S. Department of Transportation (DOT) specification 6M container is the package of choice for most of these shipments. However, the 6M does not conform to the Type B packaging requirements in the *Code of Federal Regulations* (10CFR71¹) and, for that reason, is being phased out for use in the secure transportation system of DOE. BWXT Y-12 is currently developing a package to replace the DOT 6M container for HEU disposition shipping campaigns. The new package is based on state-of-the-art, proven, and patented insulation technologies that have been successfully applied in the design of other packages. The new package, designated the ES-3100, will have a 50% greater capacity for HEU than the 6M and will be easier to use. Engineering analysis on the new package includes detailed dynamic impact finite element analysis (FEA). This analysis gives the ES-3100 a high probability of complying with regulatory requirements.

INTRODUCTION

The shipment of material is a significant element of the HEU disposition activities under the NNSA fissile materials disposition program. The HEU Disposition Program Office (HDPO) at BWXT Y-12, in support of the NNSA Office of Fissile Materials Disposition, plans to ship quantities of fissile materials, primarily HEU, over the next 15 to 20 years. DOT 6M containers are currently the package of choice for most of these HEU shipments. However, the 6M does not conform to the U.S. Nuclear Regulatory Commission (NRC) requirements for Type B packages (10CFR71¹). It is termed a "specification" package because it follows the intent of a DOT

specification rather than being licensed as a performance-based package. Since the 6M container is non-performance based, DOE has decided to phase out the use of the 6M for type B shipments, i.e., on the DOE Safe-Secure Trailer (SST) system. The phase out will be complete between June 2005 and January 2006.

As a result of the phase out of the 6M, as well as programmatic changes that have made other current packages less applicable for HEU, the HEU Disposition Program is in need of a new package for the shipment of Type B quantities of HEU. This paper presents the latest conceptual design prepared by BWXT Y-12 to meet the needs of HEU disposition and other fissile material shipments.

NOMENCLATURE

BWXT	BWX Technologies
CFR	<i>Code of Federal Regulations</i>
CoC	Certificate of Compliance
CRT	cargo restraint transporter
CV	containment vessel
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
FEA	Finite Element Analysis
HAC	hypothetical accident conditions
HDPO	HEU Disposition Program Office
HEU	highly enriched uranium
NCT	normal conditions of transport
NNSA	National Nuclear Security Administration
NRC	U.S. Nuclear Regulatory Commission
SARP	Safety Analysis Report for Packaging
SST	Safe-Secure Trailer
Y-12	Y-12 National Security Complex

The design of the ES-3100 is similar to that of other shipping packages currently being designed by Y-12. The proposed contents of the ES-3100 dictate that this package should be a Type B package. Type B packages have two major systems, a confinement assembly and a containment boundary. For the ES-3100 (shown on Fig.1), the confinement assembly consists of a drum, insulation, an inner liner, and a top plug. The containment boundary for the ES-3100 consists of a pressure vessel (commonly referred to as a containment vessel or CV) and an O-ring seal. These systems are described below.



The primary function of the confinement assembly is to ensure that the containment vessel and its contents remain confined under both Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) as defined in 10CFR71. For HAC, the ES-3100 package must be able to withstand the rigors of not only a 30-ft drop and 40-in. puncture test, but also a dynamic crush. The dynamic crush test, as defined in the recently finalized changes to 10CFR71,² consists of dropping an 1100-lb steel plate from 30 ft onto the package in its most vulnerable orientation.

serves as a place for weld studs to be attached as well as an anchor for the inner liner. Another modification has to do with a unique drum bottom attachment, which will reduce deformation during structural testing.

A key design feature of the ES-3100 confinement assembly will be the use of a fully encapsulated insulation material. It should be noted that while it is referred to as insulation material, this material provides energy absorption during drop, crush, and puncture testing as well as thermal insulation during thermal testing. The use of an inner liner attached to the drum with angle iron creates an annular space, which is subsequently filled with an insulating material. The insulating material is poured into this cavity through a hole in the bottom of the drum. This hole is later sealed, thereby encapsulating the insulation. Encapsulated insulation has been shown on other packages to reduce life-cycle costs by reducing package refurbishment and maintenance efforts over the package lifetime.



The ES-3100 uses Kaolite 1600™ as the insulation in the encapsulation zone. This material was initially developed and patented for another shipping package designed by Y-12.

Kaolite 1600™ is a mixture of Portland cement and expanded vermiculite.³ Prior to the development and patenting of Kaolite 1600™ as insulation in Type B packages, organic materials such as Celotex™ or polyurethane foams had typically been used for insulating materials in drum-type packages. Inorganic materials, such as the Kaolite 1600™, offer distinct advantages.

First and foremost, these materials are fireproof. During HAC thermal tests on a similar package, there was no significant degradation of the insulating materials.⁴ This is in contrast to organic materials, which undergo considerable decomposition during such testing. Decomposition can lead to heat transfer via mass transfer of hot off-gases, thereby leading to unpredictable and sometimes unacceptably high temperatures at the containment boundary. Second, inorganic materials act as thermal diodes, thereby having a higher thermal conductivity than conventional materials and allowing for higher content heat loadings during normal conditions. Under HAC conditions, the moisture within the Kaolite 1600™ is vaporized to steam at about 212°F, which then escapes from the package via vent holes in the drum. This results in tremendous heat dissipation and thus more protection of the containment boundary seals. The drum inner liner becomes a heat transfer barrier (convection and radiation) during the HAC, keeping the temperature around the containment boundary close to 212°F.

Another significant feature of the confinement assembly is a neutron absorbing system (see Fig. 3). The neutron absorbing system uses Borobond4™ cast into an annular section on the inside wall of the insulation liner. This neutron absorber allows large amounts of fissile material to be carried in the ES-3100 while maintaining a criticality safe system. The use of a neutron absorbing layer in a Type B package is a new concept and has not yet undergone regulatory review.

Containment Boundary

The primary function of the CV is to maintain containment of the radioactive materials being shipped. This is accomplished through the use of a stainless steel vessel body and lid with an elastomeric O-ring seal (Fig. 3). To conform to 10CFR71¹ requirements, whole body leak rates must be maintained under NCT and HAC scenarios. For uranium materials, for which the ES-3100 is primarily being designed, whole body leak rates on the order of 1×10^{-4} ref-cm³/s must be maintained during NCT. However, for materials with greater specific activity (Ci/gm), such as plutonium, this leak rate often is required to be as low as 1×10^{-7} ref-cm³/s. The lower leak rate is achievable with the current design, but testing will be needed to prove this in the safety analyses portion of the certification process. The ES-3100 CV is designed to handle an internal pressure of 100 psig that may be generated under certain circumstances as well as handle external pressure and impact loads due to crush and drop testing. Additionally, the ES-3100 CV is designed, and will be manufactured, in accordance with the ASME B&PVC, Section III, Subsection NB.⁵

A key design feature of the ES-3100 is the size of the CV. Both the diameter and height of the CV have been optimized for bulk HEU shipments while also taking into account the size of the 3013 Pu container. As a general purpose criticality safe container, a CV diameter in the 5-in. range was chosen. The use of such a diameter limits the opportunities for loading other parts, but other packages exist for shipment of intact parts larger than 5 in. When using the standard HEU convenience cans (diameter of 4.25 in.), there is sufficient tolerance for easy loading as well as handling fixtures that might be desired for use within the CV. The ES-3100 conceptual design specifies a 5.06-in. inside diameter CV (with a tolerance of ± 0.04 in.). There is clearance outside the CV of this configuration to allow for a slightly larger CV for other applications.

To increase the payload efficiency of each container, the overall height of the CV has been designed at 31.5 in. (inside height). This height allows for the loading of up to three 10-in.-tall cans or six 4.75-in.-tall cans, including allowances for packaging materials such as spacers and plastic bagging. This height results in a 50% increase in content loading over the 6M.

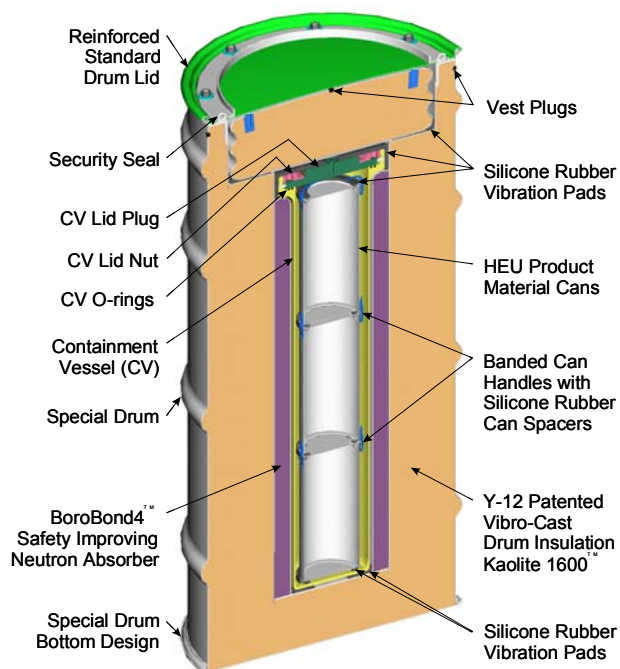


Fig. 3. ES-3100 Materials of Construction.

Innovative Content Can Handling System

Loading material into Type B packages has been accomplished in a number of ways in the past. Usually HEU materials are loaded into convenience cans, similar to food pack cans, and then lowered into the CV. Often tape "handles" are made to ease the lowering of these cans into the CV, or the can is packed into a polyethylene bag that is tied at the top, or the can is put into a nylon webbing basket.

Y-12 has recently developed an improved method of can handling - that is, use of a simple band-clamp safety strap that can easily be placed on any size can. Figure 4 shows the can handling band-clamp. Gloved personnel can readily install this band-clamp system. Other options for material loading would include a loading basket in the CV. It may be possible to incorporate a loading basket into the CV to enhance shielding, thermal protection, criticality safety, and worker protection if needed. However, it is anticipated that for the uranium materials, in general, no such loading basket would be required.

The ES-3100 loading configuration includes specially designed silicone rubber spacers be used between, below, and above the convenience cans in the CV (Fig. 4). The silicone rubber has minimal hydrogenous content, which can affect content loading limits, and has a relatively wide thermal operating range. These spacers would be inexpensive to manufacture and therefore could be either cleaned or discarded whenever they become contaminated. The spacers increase the package life by reducing shock loads and ensure that metal-to-metal rubbing, which can damage the package, does not occur.

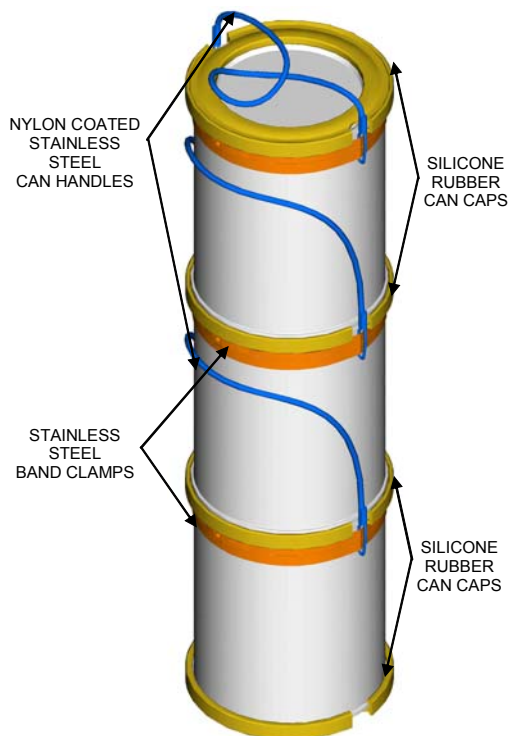


Fig. 4. Content Can Stack for ES-3100.

Additionally, Y-12 has added this type of spacer and padding material to the interface of the CV and the inner surfaces of the drum in order to reduce metal-to-metal contact in this area during handling and shipping (see Figs. 2 and 3).

RADIOACTIVE MATERIAL CONTENT OF PACKAGE

Content will be packed in various sizes of convenient cans made of stainless or tinned carbon steel. The cans will have diameters ≤ 5 in. and heights ≤ 10 in. Any combination of these cans will be allowed in a single package, as long as the total length of the can stack (with spacers) does not exceed the inside working height of the CV.

Any closure on the convenience can is allowed. Polyethylene bags may be used inside or outside any can. However, the operator must follow an H/X ratio table when determining acceptable loadings of fissile material. The H/X ratio will account for all hydrogenous material in the CV.

Because the contents will be HEU, the maximum payload inside the CV will be as follows:

- 24 kg oxide or compounds (any enrichment)
- HEU oxide in the form of UO_2 , UO_3 , or U_3O_8
- HEU compounds shall be in the form of uranyl nitrate crystals and UF_4
- 36 kg of uranium metal and alloy (any enrichment)
- HEU metal and alloy in the form of broken pieces, ingots, buttons, small castings, or fuel
- Maximum weight of all contents, including nuclear material, convenience cans, polyethylene bags, spacers, etc. limited to 90 lb

Allowances of uranium isotopes will be as follows (contingent on licensing approval):

• ^{232}U	0.040	$\mu\text{g/gU}$
• ^{233}U	0.006	g/gU
• ^{234}U	0.02	g/gU
• ^{235}U	1.00	g/gU
• ^{236}U	0.40	g/gU
• ^{238}U	1.00	g/gU

Allowances of transuranic isotopes (Np, Pu, Am, etc.) will be as follows (contingent on licensing approval):

• Concentration limit	40.0	$\mu\text{g/gU}$
• Activity limit	600,000	Bq/gU
• Np concentration	0.003	g/gU

Other allowances will be as follows:

• Moisture	15%	g/gSmpl
• Carbon	1,000	$\mu\text{g/gU}$

DESIGN ANALYSES

In the Y-12 Packaging Engineering Group, FEA has become a reliable predictive tool to determine the response of the container to the HAC conditions as defined in 10CFR71. Simulations/models of the container are formulated to a fine

detail for all components, materials, and fasteners. Over the last several years, model detail has greatly increased, with current models approaching one-half million elements. This capability has occurred with improvements in computing speed and use of multiprocessors.

A dynamic impact FEA model for a typical shipping container is shown in Fig. 5. This figure shows the details of the model that is used to simulate the consecutive 4-ft drop, 30-ft drop, and 30-ft crush tests. The package modeled in Fig. 5 is similar in design to the ES-3100 with some differences in size.

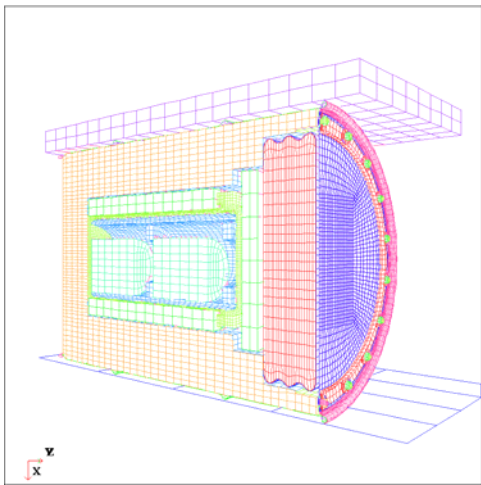


Fig. 5. Container Finite Element Analysis Model.

The analysis code that is used for these analyses (LS-DYNA⁶) has the capability to predict response from consecutive drop impact conditions. A picture of the dynamic impact FEA model of the ES-3100 showing the results of simulated drop tests is displayed in Fig. 6. This ES-3100 model withstood the HAC major drop tests required for a Type B package.

The FEA for the ES-3100 has been completed. The Y-12 analyst has worked closely with the engineer/designer as the FEA models were formulated. Once the model was formulated and checked, multiple impact simulations will be performed to verify that the ES-3100 structure can withstand the HAC conditions as required in 10CFR71.73. During this process, the “worst impact orientation” of the container will be determined. The FEA analysis results provide guidance for selecting the drop and crush orientations of the prototype container during full-scale drop testing as required in 10CFR71. Typical impact orientations that are analyzed for Type B containers at Y-12 are as follows:

- 4-ft drop, 30-ft drop, and puncture; side impact
- 4-ft drop, 30-ft drop, and puncture; end impacts

- 4-ft drop, 30-ft drop, and puncture; center-of-gravity over corner impacts
- 4-ft drop, 30-ft drop, and 30-ft crush; various orientations
- Slap down impact (various angles)

Several full-scale tests will be performed on the ES-3100 to confirm that the analytical model is reporting accurate results.

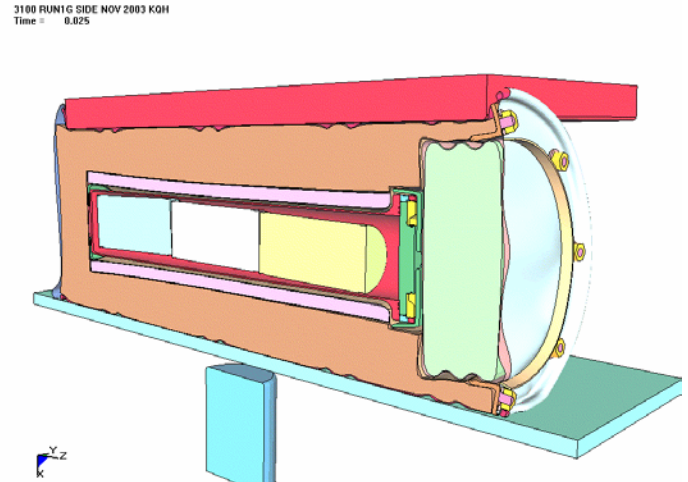


Fig. 6. ES-3100 Container Model after Two Consecutive Tests (30-ft Drop and 30-ft Crush).

ASME CODE REQUIREMENTS

Containment vessels shall be manufactured in accordance with the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code (B&PVC), Section III, Division I, Subsection NB, Class 1 components. Each CV shall be manufactured from 300-series stainless steel, preferably by seamless construction (to the extent practical), and shall be passivated per ASTM A380. Fabrication using welds will be evaluated and authorized on the design documents and drawings and will be in accordance with written equipment and procurement specifications.

Internal pressure test on the CV should be conducted to validate the single head closure design on the pressure vessel. Criteria shall be based on ASME Boiler and Pressure Vessel Code, Section III, Subsection NB, 6000.

REGULATORY COMPLIANCE

The package will comply with the NRC requirements in 10CFR71¹ and thereby comply with International Atomic

Energy Agency requirements (TS-R-1)⁷ for international Type B shipments. Specific requirements for safety that should be stressed in the new design are:

- Meet all regulatory requirements including a sequential drop and dynamic crush test.
- Ease of certification. Rely on state-of-the-art, but defensible, technology and experience in licensing Type B packages.

The ES-3100 will be licensed by the NRC. The initial Safety Analysis Report for Packaging (SARP) for the ES-3100 will specify contents as identified above. The SARP will be prepared by Y-12. The ES-3100 can be used upon receipt of a Certificate of Compliance (CoC). As other contents that need the ES-3100 are identified, Y-12 will prepare new SARPs or SARP amendments for submittal to the NRC. The ES-3100 will be authorized to transport only the materials that are specifically identified in the CoC.

BENEFITS OF THE ES-3100

Number of Shipments

The 6M container requires 50% more package shipments than the ES-3100 concept to ship the same quantity of uranium. This is also true of other Type B containers currently licensed for HEU. The ES-3100 is therefore a more efficient carrier of HEU than existing approved packages.

Package Capacity

Increased package capacity is an advantage in the SST but can also be an advantage at a facility. If a package is used for temporary storage, the larger capacity package can accommodate more material in less space.

The ES-3100 capacity is 50% greater than that of a 6M. This increased capacity has the potential to benefit both the transport system and the shipper and receiver facilities.

The increased capacity of the ES-3100 could also benefit the Plutonium Disposition Program. Typically one 3013⁸ can is transported in a package. The ES-3100 will have the capacity for two 3013 cans separated by a spacer, thus doubling the efficiency of that shipping operation.

Worker Exposure

Reduced personnel exposure will be realized with handling the ES-3100 over similar existing containers. For packages with a smaller payload capacity, more containers will have to be loaded into the SST, thus increasing operating time and exposure. Also, by loading more kilograms of uranium per SST [with the ES-3100], overall dose per kilogram of uranium loaded will be lower.

The ES-3100 will have fewer bolts than comparable licensed containers (a total of 1 inner and 8 outer closure bolts,

compared to as many as 30 bolts on other HEU packages), and it will be simpler to use. Based on this, the ES 3100 will require less time to operate and will thus be safer from a personnel exposure standpoint.

One feature in particular plays a key role in worker dose - that is, fully encapsulated insulation. This ensures that there is no radioactive contamination on the airborne insulation particles. Any small areas that can be accessed by minute particles but cannot be easily cleaned or accessed by human hands, etc. should be avoided. To this end, using welded seams to seal gaps at metal-to-metal intersections and other such manufacturing processes may have justifiable initial cost when one considers the savings realized over the lifetime of the package.

Reduced Package Inventory

Purchasing fewer packages to handle projected demand is a distinct advantage. For HEU in 10-in.-long cans (as those being shipped in the HEU Disposition Program), only one can would fit in similar existing package (ES-2100) as opposed to three cans per ES-3100. For other length cans, the loading ratio for cans is 3 to 2 for an ES-3100 compared to most other existing containers. For a typical 4-year HEU disposition shipping campaign, about 300 fewer ES-3100s will have to be purchased than with the existing package.

Reduced Footprint

A longer package has the advantage of carrying more content for the same or smaller footprint. Since floor space is a critical issue for facilities and trucks, a package that maximizes height (and thus contents), without making handling a problem, will be a more optimal package.

The ES-3100 is about 11 in. longer than the existing ES-2100 container. That increased length allows a more flexible loading configuration without sacrificing handling ability. Package handling is accomplished by using standard 30-gal drum handling equipment. Five ES-3100s can fit on a standard 4-ft pallet.

Handling Considerations

The ES-3100 has a single screw CV head closure. This will be easier and quicker to engage and tighten than a CV with 8 to 12 head bolts as in other licensed Type B packages. Thus the ES-3100 will require less effort to use during loading and unloading operations, during refurbishment, and in most handling activities associated with a Type B package. A substantial savings in time and operating cost will be realized over the expected lifetime of the HEU Disposition Program.

Annual Maintenance and Refurbishment Cost

Most shipping packages in use today have a high annual maintenance and refurbishment cost. The fiber board and cork

insulation must be inspected, with some possible replacement during annual refurbishment. This inspection, rejection, and replacement of major items in many shipping packages have increased the user operating cost. The ES-3100 with its encapsulated Kaolite 1600™ insulation is not likely to require rejection or replacement. The ES-3100 silicone rubber vibration absorber pads and spacers also have a long life, thus the annual maintenance and refurbishment cost would be minimized.

DEVELOPMENT SCHEDULE

The ES-3100 development program began with conceptual design work in late 2002. Conceptual designs were complete in March 2003 along with evaluations of the cost benefit of developing this container versus using existing containers.⁹ A decision to proceed with full-scale package development was made in May 2003. A license for use is expected around July 2005 with full implementation by January 2006.

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The authors wish to express their appreciation to the members of the Y-12 Packaging Engineering Group, the Y-12 Nuclear Criticality Safety Group, and the Y-12 Engineering Analysis Group for their efforts in developing new applications of materials for use in Type B, drum-type shipping containers. The materials new to this application (Kaolite™ and Borobond™) enhance performance under accident conditions and allow greater capacity of individual containers than has been available in the past. Mr. Matthew R. Feldman, who is now on staff at the National Transportation Research Center of the Oak Ridge National Laboratory, also contributed to the research leading up to the use of these materials. BWXT Y-12, LLC holds a patent for the use of a fireproof cast aggregate as insulation in drum-type shipping containers.

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